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DESIGN AND DEVELOPMENT OF DSP BASED SENSORLESS CONTROL OF INDUCTION MOTOR DRIVES USING MODEL REFERENCE ADAPTIVE SYSTEM

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ABSTRACT

The present paper deals with the speed estimation of the induction motor using observer with Model Reference Adaptive System (MRAS). The first part of the paper includes the mathematical description of the observer for the speed estimation of the induction motor. The second part describes the simulation results which are shown for different changes of the induction motor speed which confirm high dynamic properties of the induction motor drive with sensorless control. The third part describes experimental implementation using DSP controller. An adaptive state observer, MRAS is tested on two different schemes to observe rotor speed. The stability analysis and continuous and discrete models of each scheme are investigated. The high performance of these schemes is shown in simulations and experimental results.

Keywords: Model Reference Adaptive System (MRAS), Sensorless Control, reactive power

I. INTRODUCTION

Sensorless control techniques for IM drives have been widely investigated over the last two decades. The great advantages offered by sensorless control including compactness and robustness make it attractive for many industrial applications specially those operating in hostile environments. Among several strategies proposed for sensorless IM drives, model reference adaptive systems

(MRAS) are the most popular schemes employed due to their simple implementation and smaller computational effort. However, these schemes usually fail to provide a satisfactory response at low stator frequency. Much research interest has been devoted to improve the performance of MRAS-based sensorless schemes in this region of operation. Adaptive system can be defined as a system that consists of a primary feedback that takes care of process signal variations and a secondary feedback that deals with process state changes. In this definition, the primary feedback is used as in non-adaptive control, and the secondary feedback makes the system adaptive. From this definition it is clear that process state variations give rise to adaptation of the system. The aim of reacting to state changes is to attempt to maintain a high system performance, even if the process states are unknown or varying [2]. In this paper model reference adaptive system is applied to induction motor drive as a state observer.

II. MRAS BASED SPEED ESTIMATOR SCHEME USING SPACE VECTOR

The model reference adaptive system is one of the most successful adaptive control techniques applied to motor control and parameter estimation [2-3],[4-6]. In a MRAS system, some state variables, x_d ,x_q (e.g. back e.m.f components (e_{md} , e_{mq}) reactive power components (q_{md} ,q_{mq}) , rotor flux components (Ψ_{rd} , Ψ_{rq}) etc.) of the induction machine, which can be obtained as sensed variables such as stator voltage and currents, are estimated in reference model. They are then compared with state-variables $x\hat{}_d$ and $x\hat{}_q$ estimated by using adaptive model. The difference between these state-variables is then used in adaptation mechanism, which outputs the estimated value of the rotor speed (w_r) and adjusts the adaptive model until satisfactory performance is achieved. Fig.6.2 shows MRAS based speed estimator scheme using space vector. Two of the schemes will be discussed in the following sections: reactive power and back e.m.f errors are used as speed tuning signals. In these expressions i_s^- and i_u^- denote the stator voltage and stator current space vectors respectively in the stationary frame $\mathbf{e_m}$ denotes the back emf space vector also in stationary reference frame as $\Delta em = e_m - e\hat{}_m$. The symbol ^ denotes the quantities estimated by the adaptive model. Recent MRAS algorithms mentioned in this work avoid both pure integrators and low-pass filters. Reactive power scheme described below is robust to both stator and rotor resistance variations, and can even be applied at very low speeds (but not zero speed). Both of the observers (reactive power and back emf schemes) described below use monitored stator currents and stator voltages. In a voltage-source inverted-fed drive, however, it is not necessary to monitor the dc link voltage and the stator voltages since the latter can be reconstructed by using the inverter switching states.

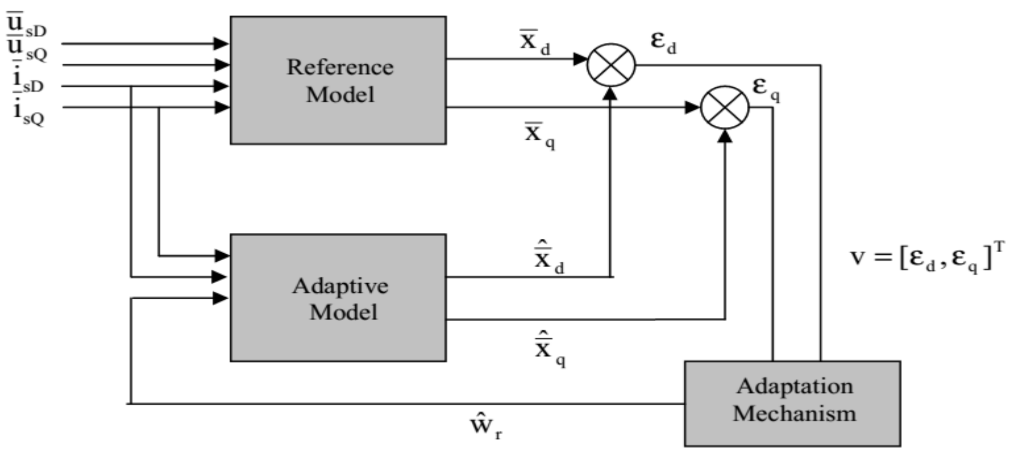


Fig.1 MRAS based speed estimator scheme

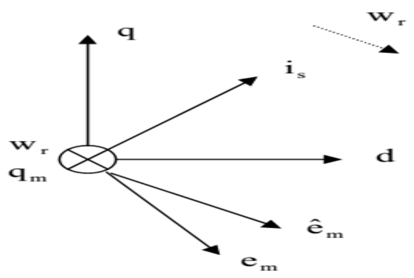


Fig.2 Coordinates in stationary reference frame

Equations for an induction motor in the stationary frame can be expressed as:

$$V_s = R_s i_s + \sigma L_s \frac{di_s}{dt} + e_m \quad \text{and} \quad \frac{di_m}{dt} = w_r \otimes i_m - \frac{1}{T_r} i_m + \frac{1}{T_r} i_s \tag{1}$$

where w_r is a vector whose magnitude is rotor electrical angular velocity, and whose direction is determined according to right hand system of coordinates as shown in Fig. 2. "⊗" denotes the cross product of vectors respectively. From Eqn.1, e_m and structure of MRAS can be derived as follows:

$$e_m = V_s - \left(R_s i_s + \sigma L_s \frac{di_s}{dt} \right), \quad e_m = L'_m \frac{di_m}{dt} \quad \text{and}$$

$$e_m = L'_m \left(w_r \otimes i_m - \frac{1}{T_r} i_m + \frac{1}{T_r} i_s \right) \tag{2}$$

We can write the above equations for the direct and quadrature-axis back emf in the following form:

$$e_{md} = L_m \frac{di_{md}}{dt} = \frac{L_m}{L_r} \frac{d\psi_{rd}}{dt} = V_{sd} - \left(R_s i_{ds} + \sigma L_s \frac{di_{sd}}{dt} \right) \tag{3}$$

$$e_{mq} = L_m \frac{di_{mq}}{dt} = \frac{L_m}{L_r} \frac{d\psi_{rq}}{dt} = V_{sq} - \left(R_s i_{sq} + \sigma L_s \frac{di_{sq}}{dt} \right) \tag{4}$$

III. REACTIVE POWER MRAS SCHEME

First let us define a new quantity q_m as the cross product of the counter EMF vector e_m and the stator current

vector i_s. That is, $\quad q_m \triangleq i_s \otimes e_m \quad (5)$

q_m is a vector, whose direction is shown in Fig.6.3, and whose magnitude q_m represents the instantaneous reactive power maintaining the magnetizing current. Substituting the Eqns (3-4) for e_m in Eqn (5) noting that $i_s \otimes i_s = 0$, we have

$$q_m = i_s \otimes \left(v_s - \sigma L_s \frac{di}{dt} \right) \qquad q_m = \frac{L_m^2}{L_r} \left((i_m \bullet i_s) w_r + \frac{1}{T_r} i_m \otimes i_s \right) \tag{6}$$

Using Eqn (6) as the reference model and the adjustable model, respectively, an MRAS system can be drawn as in Fig.3, where proportional and integral (PI) operations are utilized as the adaptation mechanism. From Eqn (6)), it is evident that the speed estimation system of Fig.3 is completely robust to the stator resistance, besides requiring no integral calculation.

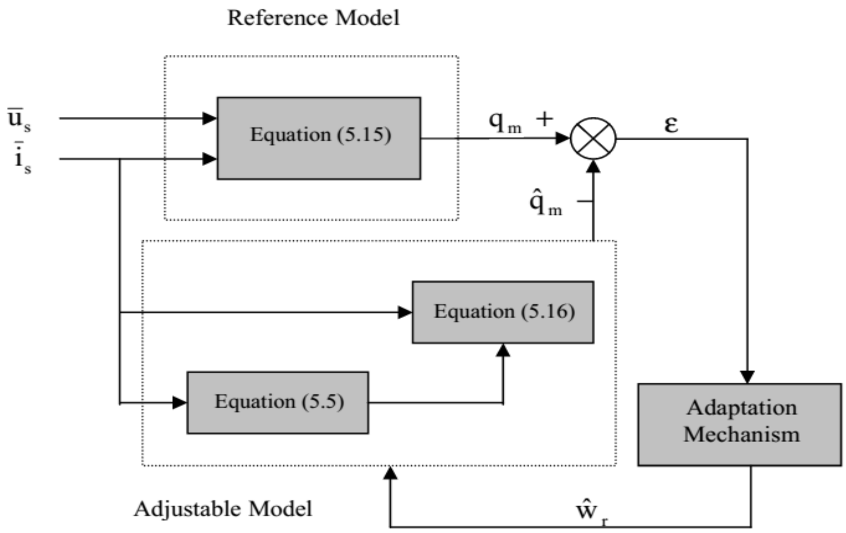


Fig.3 System structure of rotor speed observer

Notice that the representation of complex number is defined for the stator voltages and currents in the stationary reference frame i.e. $v_s = v_{sd} + j\, v_{sq}$ and $i_s^- = i_{sd} + j\, i_{sq}$

III.1 Reference Model Continuous Time Representation

The back emf of the induction motor can be expressed in the stationary frame as follows:

$$\hat{e}_{md} = \frac{L_m}{L_r}\frac{d\psi_{rd}}{dt} = v_{sd} - R_s i_{sd} - \sigma L_s \frac{di_{sd}}{dt} \qquad \hat{e}_{mq} = \frac{L_m}{L_r}\frac{d\psi_{rq}}{dt} = v_{sq} - R_s i_{sq} - \sigma L_s \frac{di_{sq}}{dt} \quad \text{and} \quad \bar{e}_m = e_{md} + je_{mq} \tag{7}$$

The reactive power of the induction motor can be computed from cross product of stator currents and back emf vectors as follows:

$$q_m = \bar{i}_s \times \bar{e}_m = \bar{i}_s \times \left(v_s - R_s \bar{i}_s - \sigma L_s \frac{d\bar{i}_s}{dt} \right) = \bar{i}_s \times \bar{v}_s - \bar{i}_s \times \sigma L_s \frac{d\bar{i}_s}{dt} \quad \text{Where,} \quad \bar{i}_s \times \bar{i}_s = i_{sd} i_{sq} - i_{sq} i_{sd} = 0 \tag{8}$$

and, leakage coefficient
$$\sigma = 1 - \frac{L_m^2}{L_r L_s} \tag{9}$$

As a result the reactive power shown can further be derived as

$$q_m = i_{sd} v_{sq} - i_{sq} v_{sd} - \sigma L_s \left(i_{sd} \frac{di_{sq}}{dt} - i_{sq} \frac{di_{sd}}{dt} \right) \tag{10}$$

III.2 Adaptive Model Continuous Time Representation

The estimated back emf computed in the adaptive model can be expressed as follows:

$$\hat{e}_{md} = \frac{L_m^2}{L_r}\frac{di_{md}}{dt} = \frac{L_m^2}{L_r}\left(-T_r\hat{w}_r i_{mq} - i_{md} + i_{sd}\right) \quad \text{and} \quad \hat{e}_{mq} = \frac{L_m^2}{L_r}\frac{di_{mq}}{dt} = \frac{L_m^2}{L_r}\left(-T_r\hat{w}_r i_{md} - i_{mq} + i_{sq}\right) \tag{11}$$

$$\hat{\bar{e}}_m = \hat{e}_{md} + j\hat{e}_{mq} \quad \text{where,} \quad Tr = Lr/Rr \tag{12}$$

T = is the rotor time constant, i_{md}, i_{mq} are computed from the following equations:

$$\frac{di_{md}}{dt} = -\hat{w}_r i_{mq} - \frac{1}{T_r} i_{md} + \frac{1}{T_r} i_{sd} \quad \text{and} \quad \frac{di_{mq}}{dt} = -\hat{w}_r i_{md} - \frac{1}{T_r} i_{mq} + \frac{1}{T_r} i_{sq} \tag{13}$$

Once the estimated back emf computed byEqns (17-18), the estimated reactive power can be computed as follows:

$$\hat{q}_m = \bar{i}_s \times \hat{\bar{e}}_m = i_{sd}\hat{e}_{mq} - i_{sq}\hat{e}_{md} \tag{14}$$

generated by adaptive model matches that generated by reference model. The speed tuning signal is the error of reactive power that can be expressed as follows:

$$\varepsilon_{\Delta e} = \bar{i}_s \times (\bar{e}_m - \hat{\bar{e}}_m) = q_m - \hat{q}_m \tag{15}$$

If the MRAS successfully maintains nearly zero error, and if the same value of Tr is used in the RAS adjustable models and in the function block for calculating w_{slip} , then we have the following relations:$w_e = \hat{w}_e$ and $T_r\, w_{slip} = \hat{T}_r\, \hat{w}_{slip}$ where variables without "^" are actual values, and ones with "^" represent the corresponding values used in the MRAS vector control systems. Thus, if $T_r \neq \hat{T}_r$, then $w_{slip} \neq \hat{w}_{slip}$, but $w_o = \hat{w}_o$, which is used for orienting the stator current vector. Therefore, complete field-orientation can be achieved even if the value of T_r is quite wrong. The error in the value of T_r, however, produces an error in the speed feedback, thus affecting the accuracy of the speed control as follows:

$$\varepsilon_W = \hat{w}_r - w_r = \{1 - T_r/\hat{T}_r\}\, w_{slip} \tag{16}$$

This also holds for the previous MRAS scheme. However, the accuracy of the speed estimation system discussed depends on the transient stator inductance and also referred magnetizing inductance. The latter quantity is not too problematic, since it does not change with temperature

III.3 Discrete time representation for DSP based system implementation

For implementation on DSP based system, the differential equations need to be transformed to difference equations. Due to high sampling frequency compared to bandwidth of the system, the numerical integration, such as forward, backward, or trapezoidal rules, can be adopted [6].

(i) Reference Model

According to Eqn (10) reference model reactive power is given as :

$$q_m = i_{sd} v_{sq} - i_{sq} v_{sd} - \sigma L_s \left(i_{sd} \frac{di_{sq}}{dt} - i_{sq} \frac{di_{sd}}{dt} \right)$$

Using backward approximation:

$$\begin{aligned} q_m(k) = {} & i_{sd}(k) v_{sq}(k) - i_{sq}(k) v_{sd}(k) - \\ & \sigma L_s \left(i_{sd}(k) \frac{i_{sq}(k) - i_{sq}(k-1)}{T} - i_{sq}(k) \frac{i_{sd}(k) - i_{sd}(k-1)}{T} \right) \end{aligned} \tag{17}$$

And this equation can be further simplified as:

$$\begin{aligned} q_m(k) = {} & i_{sd}(k) v_{sq}(k) - i_{sq}(k) v_{sd}(k) - \\ & \frac{\sigma L_s}{T} \left(i_{sd}(k-1) i_{sq}(k) - i_{sd}(k) i_{sq}(k-1) \right) \end{aligned} \tag{18}$$

where T is the sampling time.

(ii) Adaptive Model

According to (14), reactive power in adaptive model is derived as :

$$\hat{q}_m = \bar{i}_s \times \hat{e}_m = i_{sd} \hat{e}_{mq} - i_{sq} \hat{e}_{md}$$

whose discrete-time representation is:

$$\hat{q}_m(k) = i_{sd}(k) \hat{e}_{mq}(k) - i_{sq}(k) \hat{e}_{md}(k) \tag{19}$$

In order to compute e^$_{md}$ (k) and e^mq (k) consider their continuous time representations

$$\hat{e}_{md} = \frac{L_m^2}{L_r} \frac{di_{md}}{dt} = \frac{L_m^2}{L_r} \left(-T_r \hat{w}_r i_{mq} - i_{md} + i_{sd} \right) \quad \text{and} \quad \hat{e}_{mq} = \frac{L_m^2}{L_r} \frac{di_{mq}}{dt} = \frac{L_m^2}{L_r} \left(-T_r \hat{w}_r i_{md} - i_{mq} + i_{sq} \right) \tag{20}$$

which have the discrete-time representations as;

$$\hat{e}_{md}(k) = \frac{L_m^2}{L_r} \left(-T_r \hat{w}_r(k) i_{mq}(k) - i_{md}(k) + i_{sd}(k) \right) \quad \text{and} \quad \hat{e}_{mq}(k) = \frac{L_m^2}{L_r} \left(-T_r \hat{w}_r(k) i_{md}(k) - i_{mq}(k) + i_{sq}(k) \right) \tag{21}$$

and $i_{md}(k)$, $i_{mq}(k)$ can be solved by using trapezoidal integration method which yields continuous time representation

$$\frac{di_{md}}{dt} = -\hat{w}_r i_{mq} - \frac{1}{T_r} i_{md} + \frac{1}{T_r} i_{sd} \quad \text{and} \quad \frac{di_{mq}}{dt} = -\hat{w}_r i_{md} - \frac{1}{T_r} i_{mq} + \frac{1}{T_r} i_{sq} \tag{22}$$

and discrete-time representation as;

$$i_{md}(k) = i_{md}(k-1) \left[-\frac{T^2}{2} \hat{w}_r^2(k) + 1 - \frac{T}{T_r} + \left(\frac{T}{T_r} \right)^2 \right] - i_{mq}(k-1) \hat{w}_r(k) \left[T - \frac{T^2}{T_r} \right] + i_{sd}(k) \left[\frac{T}{T_r} - \frac{T^2}{2T_r^2} \right] - i_{sq}(k) \hat{w}_r(k) \left[\frac{T^2}{2T_r} \right] \tag{23}$$

$$i_{mq}(k) = i_{mq}(k-1) \left[-\frac{T^2}{2} \hat{w}_r^2(k) + 1 - \frac{T}{T_r} + \left(\frac{T}{T_r} \right)^2 \right] - i_{md}(k-1) \hat{w}_r(k) \left[T - \frac{T^2}{T_r} \right] + i_{sq}(k) \left[\frac{T}{T_r} - \frac{T^2}{2T_r^2} \right] - i_{sd}(k) \hat{w}_r(k) \left[\frac{T^2}{2T_r} \right] \tag{24}$$

(iii) Per unit, discrete time representation

For the sake of generality, the per unit concept is used in all equations. However, for the simplicity the same variables are also used in the per unit representations.

Reference Model

Dividing (6.34) by base power of V_b I_b, then its per unit representation is as follows:

$$q_m(k) = i_{sd}(k)v_{sq}(k) - i_{sq}(k)v_{sd}(k) - K_1\left(i_{sd}(k-1)i_{sq}(k) - i_{sd}(k)i_{sq}(k-1)\right) \tag{25}$$

Rearranging (25) to have the one in (26),

$$q_m(k) = i_{sd}(k)\left(v_{sq}(k) - K_1 i_{sq}(k-1)\right) - i_{sq}(k)\left(v_{sd}(k) + K_1 i_{sd}(k-1)\right) pu \tag{26}$$

Where , $K_1 = (\sigma L_s I_b)/(T V_b)$, V_b is base voltage, and I_b is base current

Adaptive Model

Dividing Eqn (21) by base voltage Vb, then yields

$$\hat{e}_{md}(k) = K_2\left(-K_3\hat{w}_r(k)i_{mq}(k) - i_{md}(k) + i_{sd}(k)\right) pu \quad \text{and} \quad \hat{e}_{mq}(k) = K_2\left(-K_3\hat{w}_r(k)i_{md}(k) - i_{mq}(k) + i_{sq}(k)\right) pu \tag{27}$$

$$\text{where } K_2 = \frac{L_m^2 I_b}{L_r T_r V_b},\ K_3 = T_r w_b = \frac{L_r w_b}{R_r} \text{ and } w_b = 2\pi f_b$$

is base electrical angular velocity. Similarly, dividing Eqns (28) and (29) by base current I_b , then yields

$$i_{md}(k) = i_{md}(k-1)\left[-K_4\hat{w}_r^2(k) + K_5\right] - i_{mq}(k-1)\hat{w}_r(k)K_6 + i_{sd}(k)K_7 - i_{sq}(k)\hat{w}_r(k)K_8 \tag{28}$$

$$i_{mq}(k) = i_{mq}(k-1)\left[-K_4\hat{w}_r^2(k) + K_5\right] - i_{md}(k-1)\hat{w}_r(k)K_6 + i_{sq}(k)K_7 - i_{sd}(k)\hat{w}_r(k)K_8 \tag{29}$$

$$\text{where, } K_4 = \frac{w_b^2 T^2}{2},\ K_5 = 1 - \frac{T}{T_r} + \left(\frac{T}{T_r}\right)^2,\ K_6 = w_b\left(T - \frac{T^2}{T_r}\right),\ K_7 = -\frac{T}{T_r} + \left(\frac{T}{T_r}\right)^2 \text{ and } K_8 = \frac{w_b T^2}{2} \tag{30}$$

IV SIMULATION of the MRAS SCHEME

The simulations of reactive power schemes is implemented to confirm the theoretical results using Matlab/Simulink. In these simulations the voltage and current outputs of induction machine model are used as the inputs of MRAS schemes. Two independent observers are configured to estimate the components of back emf and reactive power. The error between the outputs of the two observers is then used to derive a suitable adaptation mechanism which generates the estimated speed for the adaptive model as shown in Fig.4. In Fig.4 the adaptive model is configured according to equation (17) and the reference model is configured according to equation (18). Fig.5 and Fig.6 shows simulation results for four-quadrant speed tracking performance of the reactive power MRAS scheme with 20 hp and 5 hp induction motors. The simulations here are implemented under no-load conditions

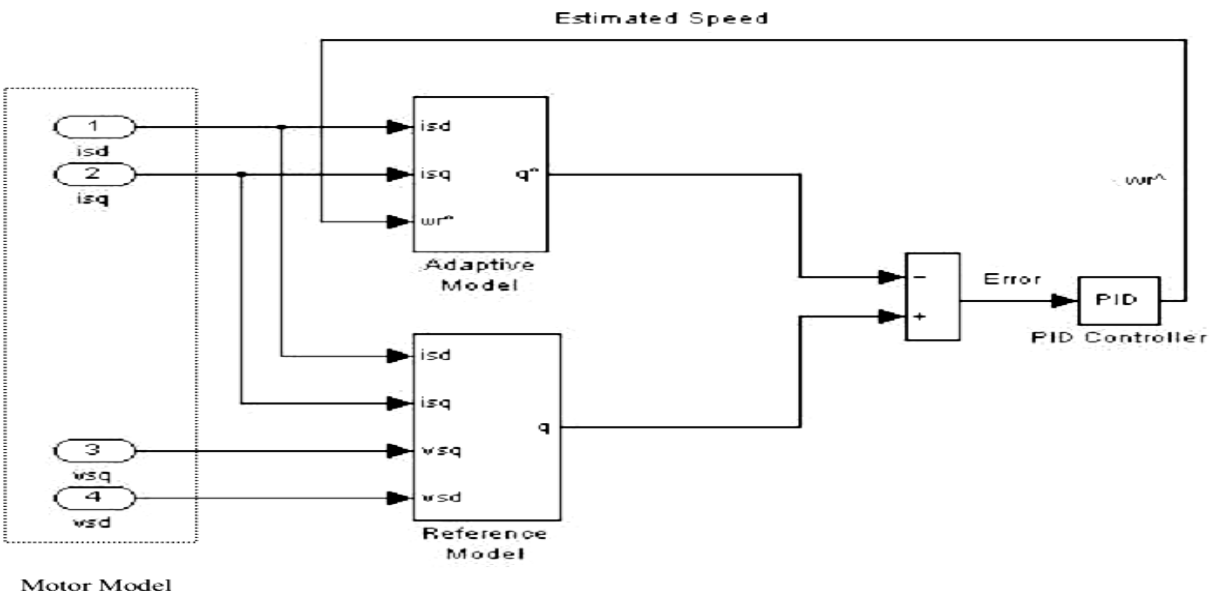
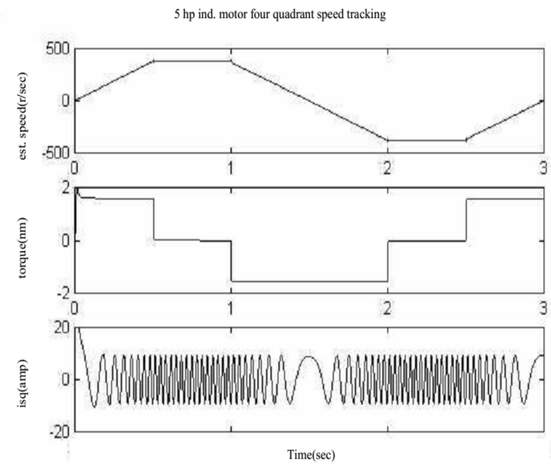
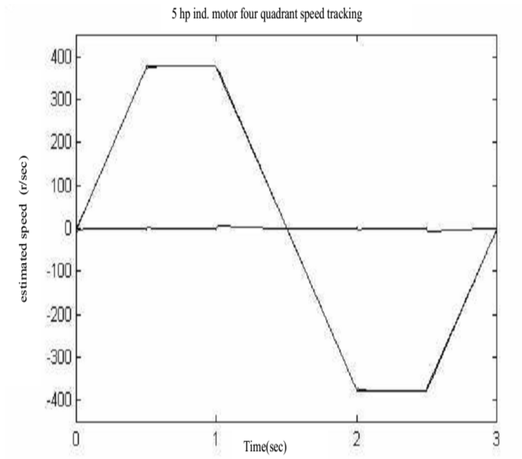


Fig.4 The Simulink model of reactive power MRAS scheme

In Fig.5 (b) and Fig.6.(b), more accurate speed estimation and speed error (difference between the actual speed and estimated speed) are shown. No-load performance of the speed observer is very high as seen in these figures even at very low speed range. Since there does not exist any immediate transient speed change due to mechanical loading, speed outputs obtained in the simulation are very smooth with negligible speed errors.

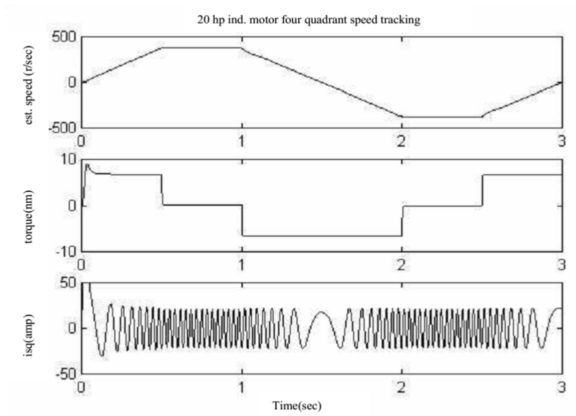


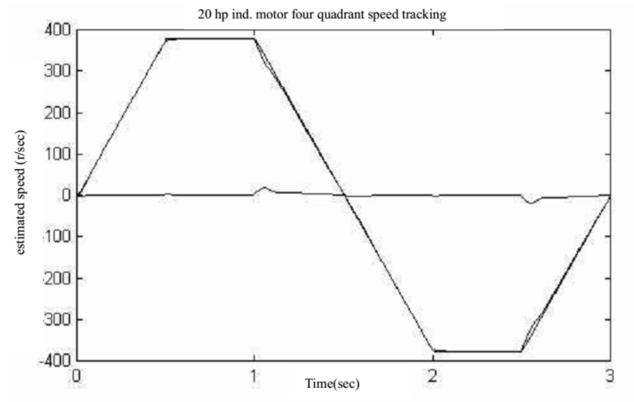
(a) Estimated speed produced due to J and i_{sq}



(b) Estimated speed, speed error

Fig.5 Four-quadrant speed reversal of 5 hp induction motor at no_load up to rated speed



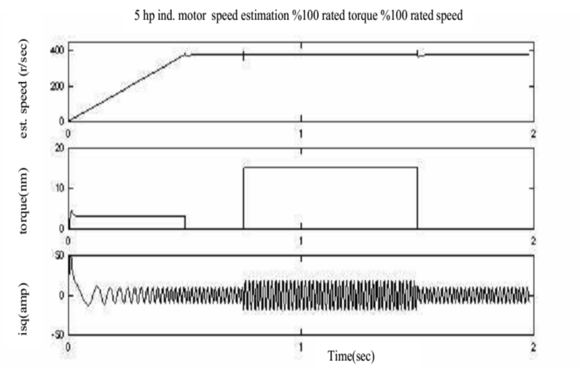


(a)Estimated speed, produced torque due to J and i_{qs}

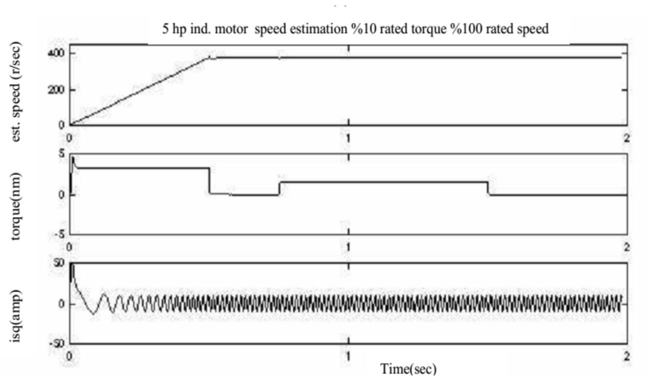
(b) Estimated speed, speed error

Fig.6 Four-quadrant speed reversal of 20 hp induction motor at no_load up to rated speed.

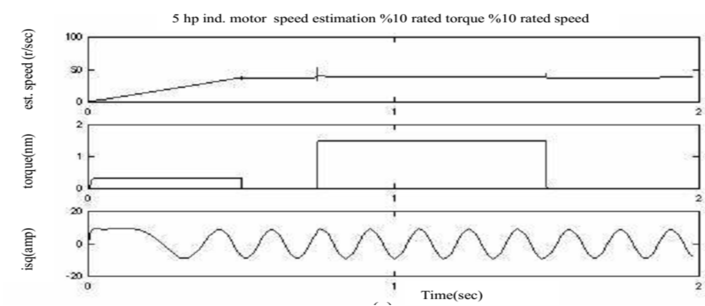
In Fig. 7 and Fig.8, the generated electromagnetic torque and q axis stator current are shown with estimated speed for both 5 hp and 20 hp induction motors at the same loading conditions.



(a) 100 % rated torque & 100 % rated speed

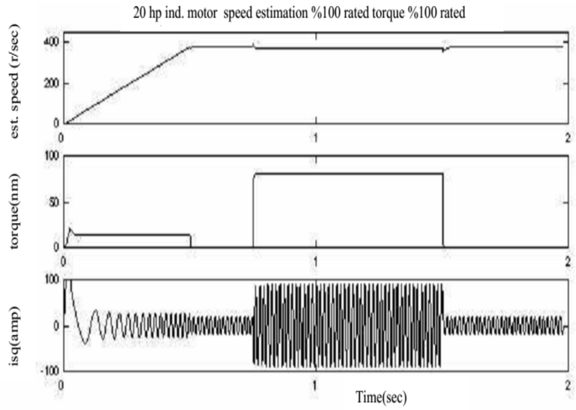


(b) %10 rated torque & %100 rated speed

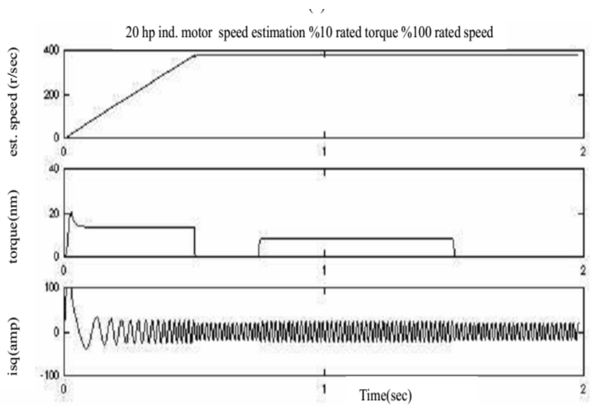


(c)%10 rated torque & %10 rated speed

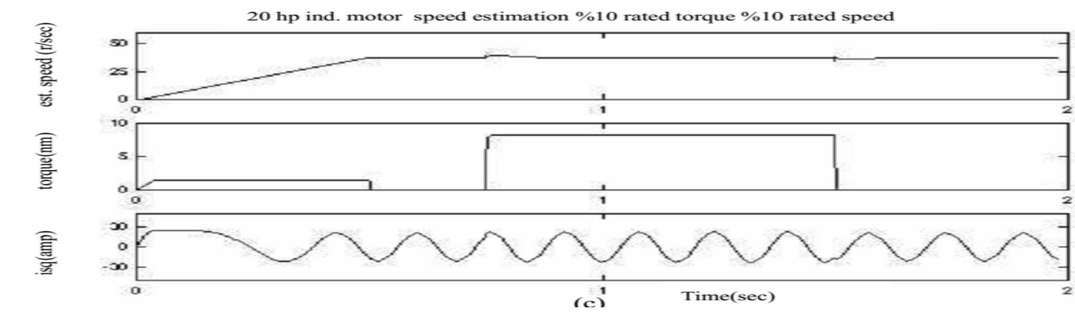
Fig.7. 5hp induction motor estimated speed speed using reactive power MRAS scheme, applied torque and stator q-axis current



(a)%100 rated torque, %100 rated speed



(b) %10 rated torque, %100 rated speed



(c)%10 rated torque, %10 rated speed

Fig.8 20 hp induction motor estimated speed using reactive power MRAS scheme, applied torque and stator q-axis current

V. EXPERIMENTAL RESULTS AND CONCLUSION

A state estimator made by using MRAS has been tested experimentally as well. The experimental data; the real time stator voltages and currents are obtained from the setup is processed by Matlab in the host computer where the associated MRAS program is running. The outputs of the processing are displayed in Figs.9. Gains of PI can be changed to improve the settling time, overshoot, rise-time, etc of the speed waveform while the system is going through the transient-state. The steady-state accuracy of MRAS meet the expectations and quite successful. Also, Fig.6.18 shows the speed tracking performance of the back emf MRAS scheme. It is seen that this tracking performance of the speed estimator seems to be quite satisfactory. The simulations and experimental works show the great promise of the studied MRAS schemes

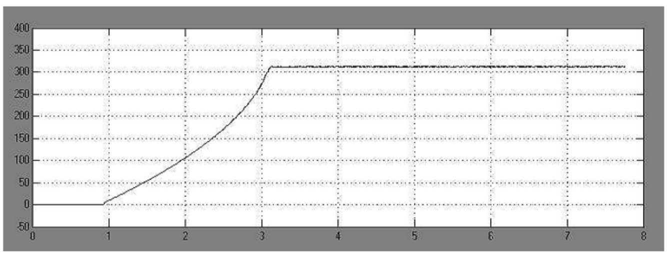


Fig 9 Rotor speed estimated by MRAS experimentally

VI. REFERENCES

1. G. Yang and T. Chin "Adaptive-Speed identification scheme for a vector controlled speed sensorless inverter induction motor drive", IEEE Tran. IA,vol. 29, no.4, pp.820-825, 1993
2. M.Elbuluk,N.Langovsky and D.Kankam "Design and Implementation of a Closed Loop Observer and Adaptive Controller for Induction Motor Drives" IEEE Tran. IA vol. 34 no. 3 pp. 435-443, May/June 1998
3. H.Tajima, Y.Hori "Speed Sensorless Field Orientation Control of the Induction Machine" IEEE Tran. IA vol. 29, no. 1, pp. 175-180, Feb.1993
4. Colin Schauder "Adaptive Speed Identification for Vector Control of Induction Motor without Rotational Transducers" IEEE Tran. IA vol. 28, no.5, pp. 1054-1061, Oct.1992
5. F.Z.Peng, T.Fukao "Robust Speed Identification for Speed Sensorless Vector Control of Induction Motors" IEEE Tran. IA vol. 30, no. 5, pp.1234-1239, Oct.1994
6. L.Zhen and L. Xu "Sensorless Field Orientation Control of Induction Machines Based on Mutual MRAS Scheme" IEEE Tran. IE vol. 45 no. 5, pp.824-831, October 1998.
7. Pradeep B Jyoti, J.Amarnath and D.Subbarayudu, "Application of Neuro-Fuzzy Controller In Torque Ripple Minimization of Vector Controlled Vsi Induction Motor Drive" International Journal of Electrical Engineering & Technology (IJEET), Volume 4, Issue 3, 2013, pp. 121 - 127, ISSN Print : 0976-6545, ISSN Online: 0976-6553.
8. Pradeep B Jyoti, J.Amarnath and D.Subbarayudu, "The Scheme of Three-Level Inverters Based on Svpwm Over modulation Technique For Vector Controlled Induction Motor Drives" International Journal of Electrical Engineering & Technology (IJEET), Volume 4, Issue 2, 2013, pp. 245 - 260, ISSN Print : 0976-6545, ISSN Online: 0976-6553.